ANNEX N

Methodology for Estimating N_2O Emissions from Agricultural Soil Management

Nitrous oxide (N_2O) emissions from agricultural soil management covers activities that add nitrogen to soils, and thereby enhance natural emissions of N_2O. The IPCC methodology (IPCC/UNEP/OECD/IEA 1997, IPCC 2000), which is used here, divides this source category into three components: (1) direct N_2O emissions from managed soils; (2) direct N_2O emissions from pasture, range, and paddock livestock manure; and (3) indirect N_2O emissions from soils induced by applications of nitrogen.

There are five steps in estimating N_2O emissions from agricultural soil management. First, the activity data are derived for each of the three components. Note that some of the data used in the first component are also used in the third component. In the second, third, and fourth steps, N_2O emissions from each of the three components are estimated. In the fifth step, emissions from the three components are summed to estimate total emissions. The remainder of this annex describes these steps, and data used in these steps, in detail.

Step 1: Derive Activity Data

The activity data for this source category are annual amounts of nitrogen added to soils for each relevant activity, except for histosol cultivation, for which the activity data are annual histosol areas cultivated.[1] The activity data are derived from statistics, such as fertilizer consumption data or livestock population data, and various factors used to convert these statistics to annual amounts of nitrogen, such as fertilizer nitrogen contents or livestock excretion rates. Activity data were derived for each of the three components, as described below.

Step 1a: Direct N_2O Emissions from Managed Soils

The activity data for this component include: a) the amount of nitrogen in synthetic and organic commercial fertilizers that are applied annually, b) the amount of nitrogen in livestock manure that is applied annually through both daily spread operations and the eventual application of manure that had been stored in manure management systems, c) the amount of nitrogen in sewage sludge that is applied annually, d) the amount of nitrogen in the aboveground biomass of nitrogen-fixing crops and forages that are produced annually, e) the amount of nitrogen in crop residues that are retained on soils annually, and f) the area of histosols cultivated annually.

Application of synthetic and organic commercial fertilizer: Annual commercial fertilizer consumption data for the United States were taken from annual publications of synthetic and organic fertilizer statistics (TVA 1991, 1992a, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999, 2000b, 2002) and a recent AAPFCO database (AAPFCO 2000a). These data were manipulated in several ways to derive the activity data needed for the inventory. First, the manure and sewage sludge portions of the organic fertilizers were subtracted from the total organic fertilizer consumption data because these nitrogen additions are accounted for under “manure application” and “sewage sludge application.”[2] Second, the organic fertilizer data, which are recorded in mass units of fertilizer, had to be converted to mass units of nitrogen by multiplying by the average organic fertilizer nitrogen contents provided in the annual fertilizer publications. These nitrogen contents are weighted average values, so they vary from year-to-year (ranging from 2.3 percent to 3.9 percent over the period 1990 through 2001). The synthetic fertilizer data are recorded in units of nitrogen, so these data did not need to be converted. Lastly, both the synthetic and organic fertilizer consumption data are recorded in “fertilizer year” totals (i.e., July to June); therefore, the data were converted to calendar year totals. This was done by assuming that approximately 35 percent of fertilizer usage occurred from July to December, and 65 percent from January to June (TVA 1992b). July to December values were

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[1] Histosols are soils with a high organic carbon content. All soils with more than 20 to 30 percent organic matter by weight (depending on the clay content) are classified as histosols (Brady and Weil 1999).

[2] Organic fertilizers included in these publications are manure, compost, dried blood, sewage sludge, tankage, and “other.” (Tankage is dried animal residue, usually freed from fat and gelatin). The manure and sewage sludge used as commercial fertilizer are accounted for elsewhere, so these were subtracted from the organic fertilizer statistics to avoid double counting.

not available for calendar year 2001, so a "least squares line" statistical extrapolation using the previous eleven years of data was used to arrive at an approximate value. Annual consumption of commercial fertilizers—synthetic and non-manure/non-sewage organic—in units of nitrogen and on a calendar year basis are presented in Table N-1.

Application of livestock manure: To estimate the amount of livestock manure nitrogen applied to soils, it was assumed that all of the manure produced by livestock would be applied to soils with two exceptions. These exceptions were: (1) the portion of poultry manure that is used as a feed supplement for ruminants, and (2) the manure that is deposited on soils by livestock on pasture, range, and paddock. In other words, all of the manure that is managed, except the portion of poultry manure that is used as a feed supplement, is assumed to be applied to soils. The amount of managed manure for each livestock type was calculated by determining the population of animals that were on feedlots or otherwise housed in order to collect and manage the manure. In some instances, the number of animals in managed systems was determined by subtracting the number of animals in pasture, range, and paddock from the total animal population for a particular animal type.

Annual animal population data for all livestock types, except horses and goats, were obtained for all years from the USDA National Agricultural Statistics Service (USDA 1994b,c; 1995a,b; 1998a,c; 1999a-c; 2000a-g; 2001b-g; 2002b-g). Horse population data were obtained from the FAOSTAT database (FAO 2002). Goat population data for 1992 and 1997 were obtained from the Census of Agriculture (USDA 1999d); these data were interpolated and extrapolated to derive estimates for the other years. Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the Census of Agriculture (USDA 1999e).

Information regarding the percentage of manure handled using various manure management systems for dairy cattle, beef cattle, and sheep was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, National Agricultural Statistics Service, and other experts (Poe et al. 1999, Anderson 2000, Deal 2000, Johnson 2000, Miller 2000, Milton 2000, Stettler 2000, Sweeten 2000, Wright 2000). Information regarding the percentage of manure handled using various manure management systems for swine, poultry, goats, and horses was obtained from Safley et al. (1992). A more detailed discussion of manure management system usage is provided in Annex M.

Once the animal populations for each livestock type and management system were estimated, these populations were then multiplied by an average animal mass constant (USDA 1996, USDA 1998d, ASAE 1999, Safley 2000) to derive total animal mass for each animal type in each management system. Total Kjeldahl nitrogen[3] excreted per year for each livestock type and management system was then calculated using daily rates of nitrogen excretion per unit of animal mass (USDA 1996, ASAE 1999). The total poultry manure nitrogen in managed systems was reduced by the amount assumed to be used as a feed supplement (i.e., 4.2 percent of the managed poultry manure; Carpenter 1992). The annual amounts of Kjeldahl nitrogen were then summed over all livestock types and management systems to derive estimates of the annual manure nitrogen applied to soils (Table N-2).

Application of sewage sludge: Estimates of annual nitrogen additions from land application of sewage sludge were derived from periodic estimates of sludge generation and disposal rates that were developed by EPA. Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works. Based on a 1988 questionnaire returned from 600 publicly owned treatment works (POTWs), the EPA estimated that 5.4 million metric tons of dry sewage sludge were generated by POTWs in the United States in that year (EPA 1993). Of this total, 33.3 percent was applied to land, including agricultural applications, compost manufacture, forest land application, and the reclamation of mining areas. A subsequent EPA report (EPA 1999) compiled data from several national studies and surveys, and estimated that approximately 6.7 and 6.9 million metric tons of dry sewage sludge were generated in 1996 and 1998, respectively, from all treatment works, and projected that approximately 7.1 million metric tons would be generated in 2000. The same study concluded that 60 percent of the sewage sludge generated in 1998 was applied to land (based on the results of a 1995 survey), and projected that 63 percent would be land applied in 2000. These EPA estimates of sludge generation and percent land applied were linearly interpolated to derive estimates for each year in the 1990 to 2000 period. To estimate annual amounts of nitrogen applied, the annual amounts of dry sewage sludge applied were multiplied by an average nitrogen content of 3.3 percent (Metcalf and Eddy, Inc. 1991). Estimates for the year 2001 were held constant at the year 2000 level,

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[3] Total Kjeldahl nitrogen is a measure of organically bound nitrogen and ammonia nitrogen in both the solid and liquid wastes.

as no new data were available (Bastian 2002). Final estimates of annual amounts of sewage sludge nitrogen applied to land are presented in Table N-1.

Production of nitrogen-fixing crops and forages: Annual production statistics for beans, pulses, and alfalfa were taken from U.S. Department of Agriculture crop production reports (USDA 1994a, 1998b, 2000i, 2001a, 2002). Annual production statistics for the remaining nitrogen-fixing forages (i.e., the major non-alfalfa forage crops, specifically red clover, white clover, birdsfoot trefoil, arrowleaf clover, and crimson clover) were derived from information in a book on forage crops (Taylor and Smith 1995, Pederson 1995, Beuselinck and Grant 1995, Hoveland and Evers 1995), and personal communications with forage experts (Cropper 2000, Evers 2000, Gerrish 2000, Hoveland 2000, and Pederson 2000).

The production statistics for beans, pulses, and alfalfa were in tons of product, which needed to be converted to tons of aboveground biomass nitrogen. This was done by multiplying the production statistics by one plus the aboveground residue to crop product mass ratios, dry matter fractions, and nitrogen contents. The residue to crop product mass ratios for soybeans and peanuts, and the dry matter content for soybeans, were obtained from Strehler and Stützle (1987). The dry matter content for peanuts was obtained through personal communications with Ketzis (1999). The residue to crop product ratios and dry matter contents for the other beans and pulses were estimated by taking averages of the values for soybeans and peanuts. The dry matter content for alfalfa was obtained through personal communications with Karkosh (2000). The IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997) was used for all beans, pulses, and alfalfa.[4]

The production statistics for the non-alfalfa forage crops were derived by multiplying estimates of areas planted by estimates of annual yields, in dry matter mass units. These derived production statistics were then converted to units of nitrogen by applying the IPCC default nitrogen content of 3 percent (IPCC/UNEP/OECD/IEA 1997).

The final estimates of annual aboveground biomass production, in units of nitrogen, are presented in Table N-3. The residue to crop product mass ratios and dry matter fractions used in these calculations are presented in Table N-6.

Retention of crop residue: It was assumed that 90 percent of residues from corn, wheat, barley, sorghum, oats, rye, millet, soybeans, peanuts, and other beans and pulses are left on the field after harvest (e.g., rolled into the soil, chopped and disked into the soil, or otherwise left behind) (Karkosh 2000).[5] It was also assumed that 100 percent of unburned rice residue is left on the field.[6]

The derivation of crop residue nitrogen activity data was very similar to the derivation of nitrogen-fixing crop activity data. Crop production statistics were multiplied by aboveground residue to crop product mass ratios, residue dry matter fractions, residue nitrogen contents, and the fraction of residues left on soils. Annual production statistics for all crops except rice in Florida were taken from U.S. Department of Agriculture reports (USDA 1994a, 1998b, 2001a, 2002). Production statistics for rice in Florida, which are not recorded by USDA, were estimated by applying an average rice crop yield for Florida (Smith 2001) to annual Florida rice areas (Schueneman 1999, 2001, Deren 2002). Residue to crop product ratios for all crops were obtained from, or derived from, Strehler and Stützle (1987). Dry matter contents for wheat, rice, corn, and barley residue were obtained from Turn et al. (1997). Soybean and millet residue dry matter contents were obtained from Strehler and Stützle (1987). Peanut, sorghum, oat, and rye residue dry matter contents were obtained through personal communications with Ketzis (1999). Dry matter contents for all other beans and pulses were estimated by averaging the values for soybeans and peanuts. The residue nitrogen contents for wheat, rice, corn, and barley are from Turn et al. (1997). The nitrogen content of soybean residue is from Barnard and Kristoferson (1985), the nitrogen contents of peanut, sorghum, oat, and rye residue are from Ketzis (1999), and the nitrogen content of millet residue is from Strehler and Stützle (1987).

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[4] This nitrogen content may be an overestimate for the residue portion of the aboveground biomass of the beans and pulses. Also, the dry matter fractions used for beans and pulses were taken from literature on crop residues, and so may be underestimates for the product portion of the aboveground biomass.

[5] Although the mode of residue application would likely affect the magnitude of N_2O emissions, an emission estimation methodology that accounts for this has not been developed.

[6] Some of the rice residue may be used for other purposes, such as for biofuel or livestock bedding material. Research to obtain more detailed information regarding final disposition of rice residue, as well as the residue of other crops, will be undertaken for future inventories.

Nitrogen contents of all other beans and pulses were estimated by averaging the values for soybeans and peanuts. Estimates of the amounts of rice residue burned annually were derived using information obtained from agricultural extension agents in each of the rice-growing states (see Agricultural Residue Burning section of the Agriculture Chapter for more detail).

The final estimates of residue retained on soil, in units of nitrogen, are presented in Table N-4. The residue to crop product mass ratios, residue dry matter fractions, and residue nitrogen contents used in these calculations are presented in Table N-6.

Cultivation of histosols: Estimates of the areas of histosols cultivated in 1982, 1992, and 1997 were obtained from the USDA's *1997 National Resources Inventory* (USDA 2000h, as extracted by Eve 2001, and revised by Ogle 2002).[7] These areas were grouped by broad climatic region[8] using temperature and precipitation estimates from Daly et al. (1994, 1998), and then further aggregated to derive a temperate total and a sub-tropical total. These final areas were then linearly interpolated to obtain estimates for 1990 through 1996, and linearly extrapolated to obtain area estimates for 1998 through 2001 (Table N-5).

Step 1b: Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

Estimates of N_2O emissions from this component were based on livestock manure that is not managed in manure management systems, but instead is deposited directly on soils by animals in pasture, range, and paddock. The livestock included in this component were: dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses.

Dairy Cattle: Information regarding dairy farm grazing was obtained from communications with personnel from state Natural Resource Conservation Service offices, state universities, and other experts (Poe et al. 1999, Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000). Because grazing operations are typically related to the number of animals on a farm, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used in conjunction with the state data obtained from personal communications to determine the percentage of total dairy cattle that graze. An overall percent of dairy waste that is deposited in pasture, range, and paddock was developed for each region of the United States. This percentage was applied to the total annual dairy cow and heifer state population data for 1990 through 2001, which were obtained from the USDA National Agricultural Statistics Service (USDA 1995a; 1999a; 2000a,b; 2001b,c; 2002b,c).

Beef Cattle: To determine the population of beef cattle that are on pasture, range, and paddock, the following assumptions were made: 1) beef cows, bulls, and calves were not housed on feedlots; 2) a portion of heifers and steers were on feedlots; and 3) all beef cattle that were not housed on feedlots were located on pasture, range, and paddock (i.e., total population minus population on feedlots equals population of pasture, range, and paddock) (Milton 2000). Information regarding the percentage of heifers and steers on feedlots was obtained from USDA personnel (Milton 2000) and used in conjunction with the USDA National Agricultural Statistics Service population data (USDA 1995a; 1999a; 2000a,b; 2001b,c; 2002b,c) to determine the population of steers and heifers on pasture, range, and paddock.

Swine: Based on the assumption that smaller facilities are less likely to utilize manure management systems, farm-size distribution data reported in the *1992 and 1997 Census of Agriculture* (USDA 1999e) were used to determine the percentage of all swine whose manure is not managed (i.e., the percentage on pasture, range, and paddock). These percentages were applied to the average of the quarterly USDA National Agricultural Statistics Service population data for swine (USDA 1994b, 1998a, 2000e, 2001d; 2002d) to determine the population of swine on pasture, range, and paddock.

Sheep: It was assumed that all sheep and lamb manure not deposited on feedlots was deposited on pasture, range, and paddock (Anderson 2000). Sheep population data were obtained from the USDA National Agricultural Statistics Service (USDA 1994c, 1999c, 2000g, 2001f, 2002f). However, population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 2001 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep

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[7] These areas do not include Alaska, but Alaska's cropland area accounts for less than 0.1 percent of total U.S. cropland area, so this omission is not significant.

[8] These climatic regions were: 1) cold temperate, dry, 2) cold temperate, moist, 3) sub-tropical, dry, 4) sub-tropical, moist, 5) warm temperate, dry, and 6) warm temperate, moist.

and lamb "on feed" were not necessarily on "feedlots"; they may have been on pasture/crop residue supplemented by feed. Data for those feedlot animals versus pasture/crop residue were provided only for lamb in 1993. To calculate the populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: It was assumed that 92 percent of goat manure was deposited on pasture, range, and paddock (Safley et al. 1992). Annual goat population data by state were available for only 1992 and 1997 (USDA 1999d). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 2001. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Poultry: It was assumed that one percent of poultry manure was deposited on pasture, range, and paddock (Safley et al. 1992). Poultry population data were obtained from USDA National Agricultural Statistics Service (USDA 1995b, 1998a, 1999b, 2000c, 2000d, 2000f, 2001f, 2002f). The annual population data for boilers and turkeys were adjusted for turnover (i.e., slaughter) rate (Lange 2000).

Horses: It was assumed that 92 percent of horse manure was deposited on pasture, range, and paddock (Safley et al. 1992). Horse population data were obtained from the FAOSTAT database (FAO 2002).

For each animal type, the population of animals within pasture, range, and paddock systems was multiplied by an average animal mass constant (USDA 1996, ASAE 1999, USDA 1998d, Safley 2000) to derive total animal mass for each animal type. Total Kjeldahl nitrogen excreted per year was then calculated for each animal type using daily rates of nitrogen excretion per unit of animal mass (USDA 1996, ASAE 1999). Annual nitrogen excretion was then summed over all animal types to yield total nitrogen in pasture, range, and paddock manure (Table N-2).

Step 1c: Indirect N_2O Emissions from Soils Induced by Applications of Nitrogen

This component accounts for N_2O that is emitted indirectly from nitrogen applied as commercial fertilizer, sewage sludge, and livestock manure. Through volatilization, some of this nitrogen enters the atmosphere as NH_3 and NO_x, and subsequently returns to soils through atmospheric deposition, thereby enhancing N_2O production. Additional nitrogen is lost from soils through leaching and runoff, and enters groundwater and surface water systems, from which a portion is emitted as N_2O. These two indirect emission pathways are treated separately, although the activity data used, except for livestock manure, are identical. The activity data for commercial fertilizer and sewage sludge are the same as those used in the calculation of direct emissions from managed soils (Table N-1). The activity data for livestock manure are different from those used in other calculations. Here, total livestock manure (i.e., the sum of applied manure, manure in pasture, range, and paddock, and manure used as a livestock feed supplement) is used in the volatilization and deposition calculation; and livestock manure applied or deposited on soils (i.e., the sum of applied manure and manure in pasture, range, and paddock) in the leaching and runoff calculation. These data are presented in Table N-2.

Table N-1: Commercial Fertilizer Consumption & Land Application of Sewage Sludge (Gg N)

Fertilizer Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Synthetic	10,104	10,275	10,352	10,719	11,160	10,798	11,156	11,172	11,193	11,237	10,898	10,684
Other Organics*	5	9	6	5	8	11	13	15	13	11	10	9
Sewage Sludge	77	87	97	107	118	129	133	135	137	142	148	148

* Excludes manure and sewage sludge used as commercial fertilizer.

Table N-2: Livestock Manure Nitrogen (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Applied to Soils	2,675	2,746	2,735	2,791	2,811	2,782	2,814	2,875	2,910	2,907	2,959	2,972
Pasture, Range, & Paddock	4,148	4,167	4,256	4,304	4,412	4,474	4,467	4,331	4,244	4,199	4,136	4,100
Total Manure	6,855	6,945	7,024	7,130	7,258	7,290	7,317	7,243	7,191	7,143	7,133	7,110

Table N-3: Aboveground Biomass Nitrogen in Nitrogen-Fixing Crops and Forages (Gg)

Crop Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Soybeans	4,241	4,374	4,823	4,117	5,538	4,788	5,241	5,921	6,036	5,844	6,073	6,365
Peanuts	84	115	100	79	99	81	86	83	93	90	76	99
Dry Edible Beans	98	102	68	66	87	93	84	89	92	100	80	59
Dry Edible Peas	7	11	8	10	7	14	8	17	18	14	11	11

Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+	+	+
Lentils	3	5	5	6	6	7	4	7	6	7	9	9
Wrinkled Seed Peas	3	3	2	3	2	3	2	2	2	2	2	2
Alfalfa	1,730	1,729	1,642	1,662	1,683	1,746	1,642	1,655	1,708	1,740	1,642	1,646
Red Clover	513	513	513	513	513	513	513	513	513	513	513	513
White Clover	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735
Birdsfoot Trefoil	99	99	99	99	99	99	99	99	99	99	99	99
Arrowleaf Clover	67	67	67	65	63	61	58	56	54	52	48	50
Crimson Clover	21	21	21	19	18	17	16	14	13	12	11	9
Total	**9,600**	**9,774**	**10,082**	**9,375**	**10,850**	**10,156**	**10,488**	**11,192**	**11,368**	**11,207**	**11,298**	**11,598**

+ Less than 0.5 Gg N.

Note: Totals may not sum due to independent rounding.

Table N-4: Nitrogen in Crop Residues Retained on Soils (Gg)

Product Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Corn	957	902	1,143	765	1,213	893	1,114	1,111	1,177	1,138	1,196	1,147
Wheat	501	364	453	440	426	401	418	456	468	422	410	359
Barley	71	78	77	67	63	61	66	61	59	47	54	42
Sorghum	180	184	275	168	203	144	250	199	164	187	148	162
Oats	39	27	32	23	25	18	17	18	18	16	16	13
Rye	2	2	2	2	2	2	1	1	2	2	1	1
Millet	3	3	3	3	3	3	3	3	3	3	1	3
Rice	51	53	61	52	65	60	57	66	69	75	69	89
Soybeans	1,982	2,045	2,254	1,924	2,588	2,238	2,450	2,767	2,821	2,731	2,839	2,975
Peanuts	13	18	16	13	16	13	14	13	15	14	12	16
Dry Edible Beans	11	12	8	7	10	10	10	10	10	11	9	7
Dry Edible Peas	1	1	1	1	1	2	1	2	2	2	1	1
Austrian Winter Peas	+	+	+	+	+	+	+	+	+	+	+	0
Lentils	+	1	1	1	1	1	+	1	1	1	1	1
Wrinkled Seed Peas	+	+	+	+	+	+	+	+	+	+	+	0
Total	**3,814**	**3,689**	**4,326**	**3,466**	**4,616**	**3,845**	**4,402**	**4,709**	**4,810**	**4,650**	**4,758**	**4,817**

+ Less than 0.5 Gg N.

Note: Totals may not sum due to independent rounding.

Table N-5: Cultivated Histosol Area (Thousand Hectares)

Year	Temperate Area	Sub-Tropical Area
1990	432	192
1991	431	193
1992	429	194
1993	431	194
1994	433	195
1995	435	195
1996	437	196
1997	439	196
1998	441	197
1999	443	197
2000	445	197
2001	447	198

Table N-6: Key Assumptions for Nitrogen-Fixing Crop Production and Crop Residue

Crop	Residue/Crop Ratio	Residue Dry Matter Fraction	Residue Nitrogen Fraction
Soybeans	2.1	0.87	0.023
Peanuts	1.0	0.86	0.0106
Dry Edible Beans	1.55	0.87	0.0062
Dry Edible Peas	1.55	0.87	0.0062
Austrian Winter Peas	1.55	0.87	0.0062
Lentils	1.55	0.87	0.0062
Wrinkled Seed Peas	1.55	0.87	0.0062

Alfalfa	0	0.85	NA
Corn	1.0	0.91	0.0058
Wheat	1.3	0.93	0.0062
Barley	1.2	0.93	0.0077
Sorghum	1.4	0.91	0.0108
Oats	1.3	0.92	0.007
Rye	1.6	0.90	0.0048
Millet	1.4	0.89	0.007
Rice	1.4	0.91	0.0072

Note: For the derivation of activity data for nitrogen-fixing crop production, the IPCC default nitrogen content of aboveground biomass (3 percent) was used.

Step 2: Estimate Direct N_2O Emissions from Managed Soils Due to Nitrogen Additions and Cultivation of Histosols

In this step, N_2O emissions were calculated for each of two parts (direct N_2O emissions due to nitrogen additions and direct N_2O emissions due to histosol cultivation), which were then summed to yield total direct N_2O emissions from managed soils (Table N-7).

Step 2a: Direct N_2O Emissions Due to Nitrogen Additions

To estimate these emissions, the amounts of nitrogen applied were each reduced by the IPCC default fraction of nitrogen that is assumed to volatilize, the unvolatilized amounts were then summed, and the total unvolatilized nitrogen was multiplied by the IPCC default emission factor of 0.0125 kg N_2O-N/kg N (IPCC/UNEP/OECD/IEA 1997). The volatilization assumptions are described below.

- *Application of synthetic and organic commercial fertilizer:* The total amounts of nitrogen applied in the form of synthetic commercial fertilizers and non-manure/non-sewage organic commercial fertilizers were reduced by 10 percent and 20 percent, respectively, to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of livestock manure:* The total amount of livestock manure nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997).
- *Application of sewage sludge:* The total amount of sewage sludge nitrogen applied to soils was reduced by 20 percent to account for the portion that volatilizes to NH_3 and NO_x (IPCC/UNEP/OECD/IEA 1997, IPCC 2000).
- *Production of nitrogen-fixing crops:* None of the nitrogen in the aboveground biomass of nitrogen-fixing crops was assumed to volatilize.
- *Retention of crop residue:* None of the nitrogen in retained crop residue was assumed to volatilize.

Step 2b: Direct N_2O Emissions Due to Cultivation of Histosols

To estimate annual N_2O emissions from histosol cultivation, the temperate histosol area was multiplied by the IPCC default emission factor for temperate soils (8 kg N_2O-N/ha cultivated; IPCC 2000), and the sub-tropical histosol area was multiplied by the average of the temperate and tropical IPCC default emission factors (12 kg N_2O-N/ha cultivated; IPCC 2000).

Step 3: Estimate Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

To estimate direct N_2O emissions from soils due to the deposition of pasture, range, and paddock manure, the total nitrogen excreted by these animals was multiplied by the IPCC default emission factor (0.02 kg N_2O-N/kg N excreted) (see Table N-8).

Step 4: Estimate Indirect N_2O Emissions Induced by Applications of Nitrogen

In this step, N_2O emissions were calculated for each of two parts (indirect N_2O emissions due to volatilization of applied nitrogen and indirect N_2O emissions due to leaching and runoff of applied nitrogen), which were then summed to yield total direct N_2O emissions from managed soils.

Step 4a: Indirect Emissions Due to Volatilization

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen produced, were each multiplied by the IPCC default fraction of nitrogen that is assumed to volatilize to NH_3 and NO_x (10 percent for synthetic fertilizer nitrogen; and 20 percent for nitrogen in organic fertilizer, sewage sludge, and livestock manure). Next, the volatilized amounts of nitrogen were summed, and then the total volatilized nitrogen was multiplied by the IPCC default emission factor of 0.01 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table N-9.

Step 4b: Indirect Emissions Due to Leaching and Runoff

To estimate these emissions, first the amounts of commercial fertilizer nitrogen and sewage sludge nitrogen applied, and the total amount of manure nitrogen applied or deposited, were each multiplied by the IPCC default fraction of nitrogen that is assumed to leach and runoff (30 percent for all nitrogen). Next, the leached/runoff amounts of nitrogen were summed, and then the total nitrogen was multiplied by the IPCC default emission factor of 0.025 kg N_20-N/kg N (IPCC/UNEP/OECD/IEA 1997). These emission estimates are presented in Table N-9.

Table N-7: Direct N_2O Emissions from Managed Soils (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Commercial Fertilizers*	55	56	57	59	61	59	61	61	61	62	60	59
Livestock Manure	13	13	13	14	14	14	14	14	14	14	14	14
Sewage Sludge	+	+	+	1	1	1	1	1	1	1	1	1
Nitrogen Fixation	58	60	61	57	66	62	64	68	69	68	69	71
Crop Residue	23	22	26	21	28	23	27	29	29	28	29	29
Histosol Cultivation	3	3	3	3	3	3	3	3	3	3	3	3
Total	**153**	**155**	**161**	**154**	**172**	**162**	**169**	**176**	**178**	**176**	**176**	**177**

+ Less than 0.5 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.
* These data do not include sewage sludge and livestock manure used as commercial fertilizers, to avoid double counting.

Table N-8: Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure (Tg CO_2 Eq.)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Beef Cattle	35	35	36	37	38	39	39	38	37	37	36	36
Dairy Cows	2	2	2	2	2	1	1	1	1	1	1	1
Swine	+	1	1	+	+	+	+	+	+	+	+	+
Sheep	+	+	+	+	+	+	+	+	+	+	+	+
Goats	+	+	+	+	+	+	+	+	+	+	+	+
Poultry	+	+	+	+	+	+	+	+	+	+	+	+
Horses	2	2	2	2	2	2	2	2	2	2	2	2
Total	**40**	**41**	**41**	**42**	**43**	**44**	**44**	**42**	**41**	**41**	**40**	**40**

+ Less than 0.5 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Table N-9: Indirect N_2O Emissions (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Volatil. & Atm. Deposition	**12**	**12**	**12**	**12**	**13**	**12**	**13**	**13**	**13**	**13**	**12**	**12**
Comm. Fertilizers	5	5	5	5	5	5	5	5	5	5	5	5
Livestock Manure	7	7	7	7	7	7	7	7	7	7	7	7
Sewage Sludge	+	+	+	+	+	+	+	+	+	+	+	+
Surface Leaching & Runoff	**62**	**63**	**64**	**66**	**68**	**66**	**68**	**68**	**68**	**68**	**66**	**65**
Comm. Fertilizers	37	38	38	39	41	39	41	41	41	41	40	39
Livestock Manure	25	25	26	26	26	27	27	26	26	26	26	26

Sewage Sludge	+	+	+	+	+	+	+	+	1	1	1	1
Total	**74**	**75**	**76**	**78**	**80**	**79**	**81**	**80**	**80**	**80**	**79**	**78**

+ Less than 0.5 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Step 5: Estimate Total N_2O Emissions

In this step, total emissions are calculated by summing direct emissions from managed soils, direct emissions from pasture, range, and paddock livestock manure, and indirect emissions (Table N-10).

Table N-10: Total N_2O Emissions (Tg CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Direct Emissions from Managed Soils	153	155	161	154	172	162	169	176	178	176	176	177
Direct Emissions from Pasture, Range, and Paddock Livestock	40	41	42	42	43	44	44	42	41	41	40	40
Indirect Emissions	74	75	76	78	80	79	81	80	80	80	79	78
Total	**268**	**271**	**278**	**274**	**296**	**284**	**293**	**298**	**299**	**297**	**295**	**294**

Note: Totals may not sum due to independent rounding.